Chapter 3

Fibre Optic Communication

All of us know about the famous Hindi movie “Sholay”. One day Ram’s father announced at home that he wanted to watch that movie. Ram searched all channels in a television to see if that movie is currently being played. But unfortunately, it was not. So Ram downloaded the movie in fraction of minutes and he started playing it on his computer. Naturally Ram’s father was very happy.

This was possible because of the high speed Internet connection received through optical fibre cable broadband services. In this chapter, we will understand the basics of optical fibre, need of optical fibre communication, advantages and disadvantages of optical fibre communication. Also, we will discuss various applications of optical fibres.

OPTICAL FIBRES

Optical fibres are simple threads like human hair, made up of glass or plastic. The light propagates from one end to another end through these optical fibres.

Example: Fibre optic cables are used for data transmission in high-level data security fields of military and aerospace engineering. These are used in wiring in aircrafts, hydrophones for SONARs (sound navigation ranging) and seismic applications.

Assignment: List the different application areas where optical fibres are used.

Basic structure of an optical fibre

The basic structure of an optical fibre consists of the following parts—

(a) Core

(b) Cladding

(c) Buffer

(d) Strength member

(e) Jacket

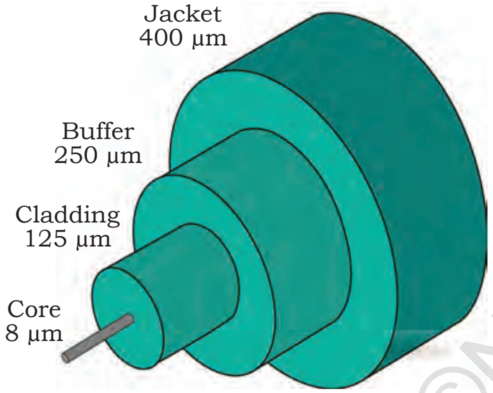


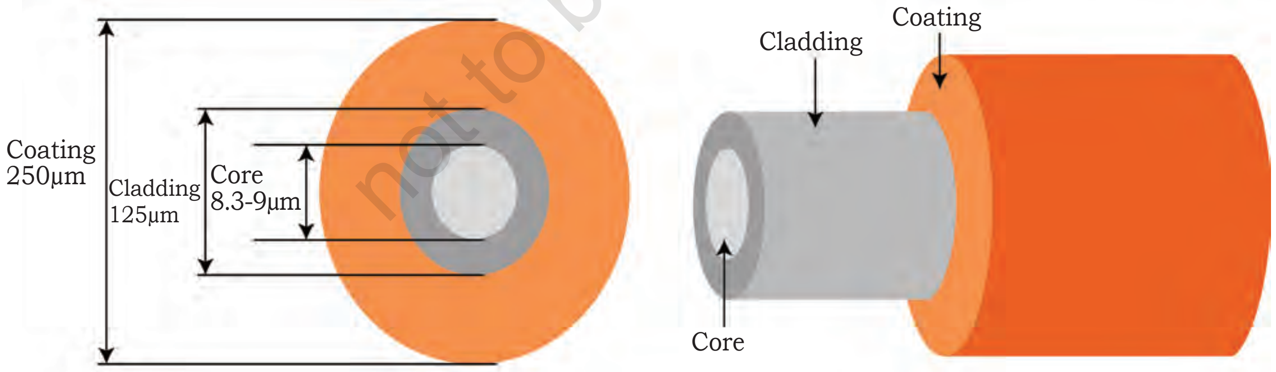
Fig. 3.2: Optical fibre structure

Core

It is the thin glass centre of the fibre where light travels. Light propagates mainly along the core of the fibre.

Cladding

It is the outer layer of optical material surrounding the core. It reflects the light back into the core. It traps the light in the core using an optical technique.



Cross sectional view of single mode fibre

Side view of single mode fibre

Fig. 3.3: Core and cladding of an optical fibre cable

Core and cladding of optical fibre are available in different diameter. Some of the core and cladding are mentioned in the Table 3.1.

Table 3.1

Optical fibre part	Single-mode optical fibre (Diameter in µm)	Multi-mode optical fibre—Step index (Diameter in µm)			Multi-mode optical fibre—Graded index (Diameter in µm)		
Core	8–10	62.5	100	1000	50	62.5	85
Cladding	125	125	140	1200	125	125	125

Buffer

Optical fibre is a combination of core and cladding. Number of fibres bind together to form cable. These fibres are coated with a protected layer known as buffer. It is made of hard-plastic coating.

Strength Member

Strength members run between the buffer and the outer jacket. It helps to increase a cable's tensile strength. It also protects the fibre against stretching and excessive bending.

Jacket

The jacket is the fibre's outer protective layer. This part must protect the fibre from the worst outside environment, including sunlight, ice, equipment accidents. Jackets are made up of plastic.

Example: The following table illustrates material used to manufacture optical fibre.

Table 3.2

Parts of optical fibre cable	Material required for manufacturing
Core	Glass or plastic
Cladding	Glass or plastic
Strength member	Stranded steel, kevlar, nylon
Buffer	Only glass, glass and polymers, polymer
Jacket	Polyethylene, polyvinyl chloride, polyurethane, polyester elastomers

Assignment: Match the following components of the fibre with their appropriate features.

Name of the components of fibre	Feature
Cladding	It reflects the light back into the core. It traps the light in the core using an optical technique.
Core	It protects the fibre from the worst outside environment.
Buffer	Buffering consists of a buffer layer in which optical fibres is attached tightly.
Strength member	It is the thin glass centre of the fibre where the light travels.
Jacket	It runs between the buffer and the outer jacket

Assignment: Identify the type of cable in Fig. 3.4 and name the different parts of cable from the following options.
Central strength member, fibres, buffer, outer jacket, core, cladding.

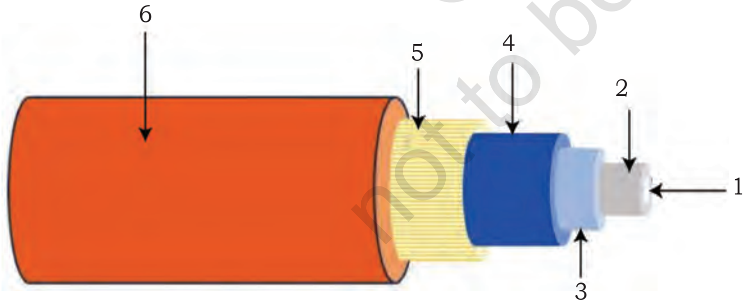


Fig. 3.4 Optical fibre cable

Importance of fibre optics communication systems

An optical fibre has various advantages over copper wire or radio system, and so it is widely used in the telecommunication industry. The following are the main advantages of optical fibres.

a. Small in size and light weight: Optical fibres are thinner than coaxial cable or bundled twisted pair cable and hence they occupy much less space in the ground when it is installed.

b. Greater bandwidth: Bandwidth of an optical fibre is higher than that of an equivalent wire transmission line.

c. Data rate: It is much higher in an optical fibre, hence more information can be carried through optical fibre than copper cables. At high frequency, data rates of 2 Gbps over 10 kilometres have been demonstrated. Coaxial cable can practically carry hundreds of Mbps over about 1 kilometre whereas twisted pair carries just a few Mbps over 1 kilometres.

d. Attenuation: It refers to the signal loss via optical fibre. Optical fibre uses light as a carrier and hence there is very less signal loss as compared to copper wire. So, long distance transmission is possible without repeaters.

e. Ruggedness and Flexibility: The optical fibre cable can be easily bent or twisted without damaging it. It is free from pollution and radiation. It is nominally affected by the nuclear radiation. Its life is longer than copper wire. It is superior to copper cable in terms of installation, transportation, storage, maintenance, strength and durability.

f. Electromagnetic Interference: Electromagnetic waves generated from electrical disturbances or electrical noises do not interfere with light signals. Even optical fibres are non-inductive and non-conductive in nature, so there is no radiation and interference in the other circuits and systems. Hence, the optical fibre system is not vulnerable to interference, impulse noise or cross-talk.

g. Secure Communication: It is difficult to tap optical fibres hence transmission is more secure and private.

h. Electrical Isolation: As optical fibres are good dielectric, hence, isolation coating is not required. Optical fibres allow transmission between two points without regard to the electrical potential between them.

i. Lower Channel Cost: The cost of channel is lower than that of the equivalent wire cable system. Thus optical fibre communication system is more economical than any communication system of other types.

j. Easy Installation: Optical Fibre cables are easier to install as compared to copper conductors of equivalent signal carrying capacity. It requires less duct space, weighs 10 to 15 times less and costs less than copper.

k. Metal Free: Optical fibre cables do not have any metal conductors, and hence they do not pose the shock hazards as in copper cables. They do not emit sparks or cause short circuits, which is important in explosive gas or flammable environments.

l. Electrical Isolation: Optical fibre allows transmission between two points irrespective of the electrical potential between them.

Generations of communication systems

The development of fibre-optic communication emerged around 1975. The enormous progress realised over a 40-year period extending from 1975 to 2018 can be grouped into several distinct generations.

In the first generation, commercial telephone systems were operated at a wavelength of 820 nm. They operated at a bit rate of 45 Mbit/s and allowed repeater spacings of up to 8-10 km. It is important to stress that even the first generation systems transmitted nearly 700 telephone calls simultaneously over a single fibre.

Second generation commercial telephone systems operated at a wavelength of 1300 nm without repeaters with single mode fibres. This provided a transmission rate of up to 45 Km.

Third generation systems operating at a wavelength of 1550 nm is anticipated, which will employ single mode fibre. It will provide transmission rate of 1.3 Gb/sec over a distance of 45 Km.

Fourth generation commercial telephone systems will have a transmission rate of 2 Gb/sec over a fibre link of 1330 Km.

Additional high bandwidth capabilities have been extended into the gigahertz range. These are glimpses of future generation of fibre optics communications.

Propagation of light wave through optical fibre

Fibre is made up of glass or plastic. The working of an optical fibre depends on the very basic principles of optics and the interaction of light with matter. To understand how light propagates through the fibre, it is necessary to understand the concept of light, and how this thin fibre carries the light through the fibre.

Nature of light

Light has a dual nature containing either particle or electromagnetic waves.

Light as a electromagnetic spectrum

In fibre optic technology, the definition of light states that:

Light is the electromagnetic radiation or energy in the wavelength range including infrared, visible, and ultraviolet.

Light is a small part of the total electromagnetic spectrum, as shown in Fig. 3.5. Light is higher in frequency and shorter in wavelength than the common radio waves. Visible light's wavelength ranges from 380 nanometres (far deep violet in color) to 750 nanometres (far deep red). Infrared radiation has longer waves than visible light. Most fibre optic systems use infrared light between 800 and 1550 nanometres. This region is referred to as near-infrared (near-IR).

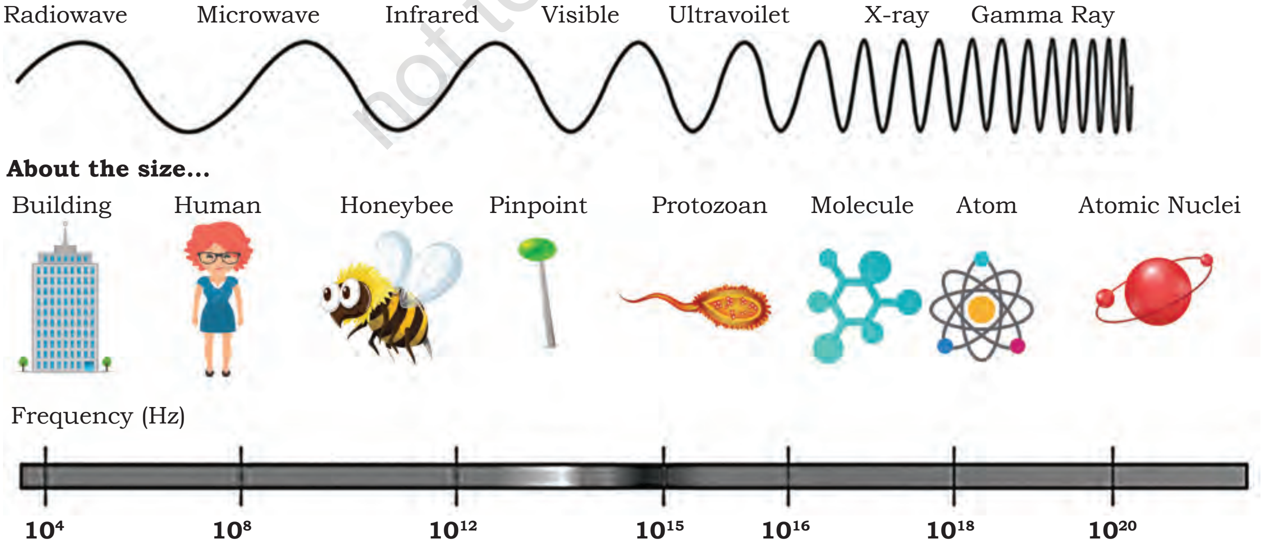


Fig. 3.5: Electromagnetic spectrum

Following is a list of the band of frequencies under which various devices operate like microwave, mobile phones, radio, television, and military.

Various bands of frequency	Applications
Radio Waves The range is 1000 meters to 1 cm.	Radio waves are found at the longest wavelengths on the electromagnetic spectrum. These are the light waves that are used to send signals to your AM/FM Radio or your television (unless you have cable).
Microwaves The range is one-tenth of a mm to 1 cm.	They have shorter wavelength than radio waves. Microwaves are used in radar and also in your microwave appliance at home that you use for heating food.
Infrared Radiation The range of infrared wavelengths is about sub-millimeters (mm) to micrometers (µm) (the size of bacteria).	Infrared radiation is what we like to describe as heat. We can't see infrared waves, but we can feel them. Your body gives off heat, so it is an emitter of infrared radiation. They have longer wavelength than visible light and are given off by every person in the form of heat.
Visible Light The range of visible wavelengths is 400 to 700 nanometers (nm).	Visible light is the light that we can see, and thus is the only light detectable by the human eye. White light is visible light, and it contains all the colours of the rainbow, from red to violet.
Ultraviolet The range for ultraviolet light is 10^{-8} to 10^{-10} meters.	Ultraviolet light is the radiation from the sun that causes sunburn when you have been outside for too long on a sunny day. You can't see ultra-violet light, so you can still get sunburnt on a cloudy day. Ultraviolet waves have more energy than visible light.
X-Rays The range for X-rays is 10^{-10} to 10^{-12} meters.	X-rays are very energetic, and are used in X-ray machines to take pictures of your bones. They are able to easily penetrate through many objects.
Gamma Rays The range for a gamma ray is in picometers (10^{-12} meters).	Gamma rays have the smallest wavelengths and the most energy of any wave in the electromagnetic spectrum. They are produced by the hottest neutron stars in the universe. On Earth, gamma waves are generated by nuclear explosions and lightning.

Light as a particle

Light also exhibits some particle-like properties. A light particle is an individual unit of energy. The energy of light depends on its frequency. The higher the frequency, the greater will be the energy. Light is also characterised by its wavelength. Shorter the wavelength, higher is the frequency.

Light travels in a straight line. It travels with the speed of 300000 Km/sec or 186,000 miles/sec in a free space. The speed of light depends on the medium through which it passes. If it passes through a plane surface then it bounces back, causing *reflection* and if it passes from one medium to another, say from air to water it bends, causing *refraction.*

Reflection

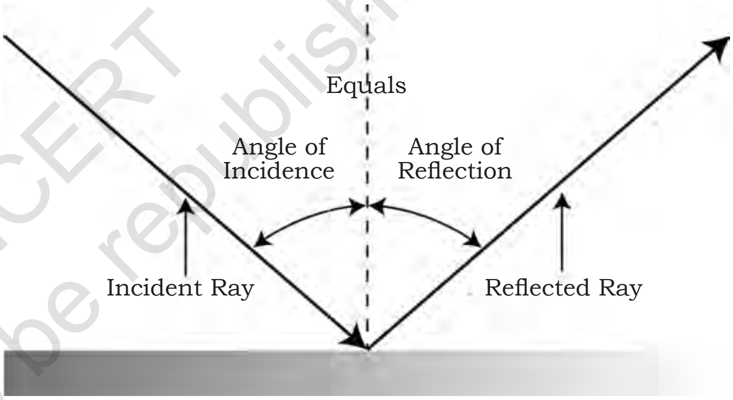


Fig. 3.6: Reflection of light

Reflection occurs when the rays of light that are deflected by a surface (sent back toward their source) are reflected. You can see your image on the mirror, because the light from the plane polished surface of the mirror gets reflected to your eyes.

The incoming light ray is called the incident ray. The light ray moving away from the surface is the reflected ray. The most important characteristic of these rays is their angles in relation to the reflecting surface. These angles are measured with respect to the normal of the surface. The normal is an imaginary line perpendicular to the surface. The angle of incidence is measured between the incident ray and the surface normal. The angle of reflection is measured between the reflected ray and the surface normal, as shown in Fig. 3.6.

The Law of Reflection states that, *the angle of incidence is equal to the angle of reflection and the incident ray, reflected ray, and the normal, all lie in the same plane.*

Refraction

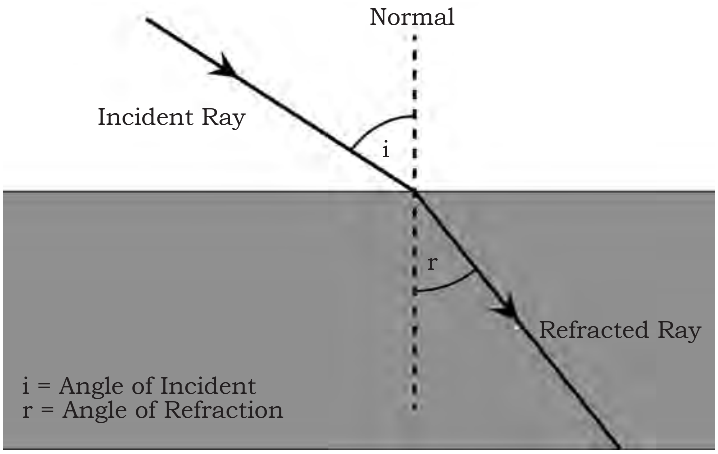


Fig. 3.7: Refraction of light

Refraction occurs when the light ray changes mediums. Light travelling through air and then going through water is an example of a light ray changing medium. The speed of the light ray changes when it enters a different medium. In most cases the direction of the light also changes. We say the light bends. Notice that a straw in a glass of water looks (from certain angles) like it is bent, as shown in Fig. 3.7.

Refractive index

The most important optical measurement for any transparent material is its refractive index (n). As a light ray passes from one transparent medium to another, it changes direction. This phenomenon is called refraction of light. How much that light ray changes its direction depends on the refractive index of the medium. The refractive index of any light-conductive medium is the ratio of the speed of light in a vacuum, to the speed of light in the medium. The speed of light in any material is always lower than in a vacuum, so all refractive indices are greater than one. The speed of light (c) is 300000 km/second. Refractive index measures how much a material refracts light. Refractive index of a material, abbreviated as ***n***, is defined as the ratio of speed of light in vacuum (c) to the velocity of light in vacuum (v).

$$n = c/v$$

Snell's law

In 1621, a Dutch physicist named Snell derived the relationship between the different angles of light (Fig. 3.8) as it passes from one transparent medium to another. When light passes from one transparent material to another, it bends according to Snell's law which is defined as:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Where,

n_1 = the refractive index of the medium the light is leaving.

θ_1 = the incident angle between the light beam and the normal (normal is 90° to the interface between two materials).

n_2 = the refractive index of the material the light is entering.

θ_2 = the refractive angle between the light ray and the normal.

Note: For the case of $\theta_1 = 0^\circ$ (i.e., a ray perpendicular to the interface) the solution is $\theta_2 = 0^\circ$ regardless of the values of n_1 and n_2. That means a ray entering a medium perpendicular to the surface is never bent.

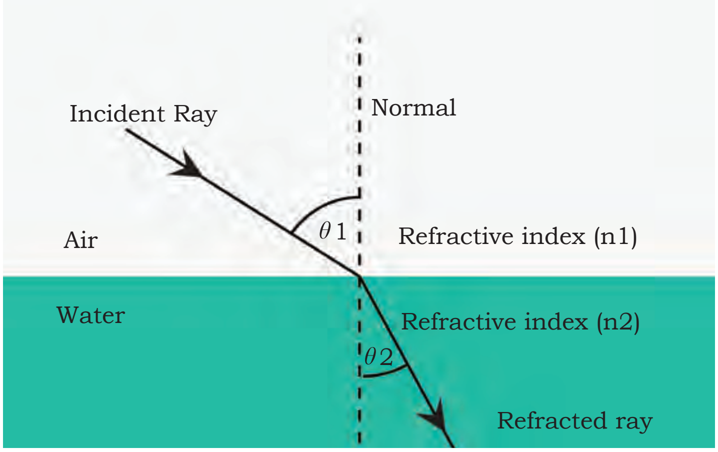


Fig. 3.8: Refraction through air-water interface

Practical Activity 1

To prove the law of reflection through a plane mirror (shown in *Fig. 3.9*).

Material Required

Soft board, white sheet of paper, optical pins, mirror, pencil, protractor, and ruler.

Procedure

1. Place the paper on the board and fix it.
2. Place the mirror vertically on the white sheet of paper and trace its edge.
3. Draw a line at right angles to the edge and of the edge of the mirror to act as the normal-ON.
4. Stating with angle *i* as 30 degree, draw an incident ray and place two pins, P and Q along it.
5. With your eyes at position shown, place two other pins R and S to coincide with the images of P and Q as seen in the mirror

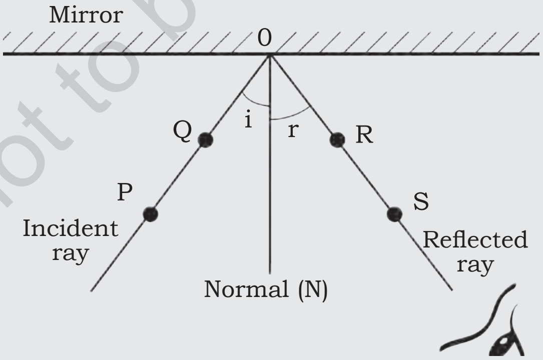


Fig. 3.9: Practical activity to prove the law of reflection

6. Remove pins R and S and join the dots left with a straight line.
7. Measure and record angle r.
8. Repeat procedure 4, 5, 6 and 7 for angles i = 35 degree, 40 degree, 45 degree, 50 degree and 55 degree.

Record the results in a table.

On carefully observing the result one will clearly see that:

1. The angle of incidence equals the angle of reflection.
2. Incident ray, reflected ray and the normal at the point of incidence lie in the same plane.
   Hence, the law of reflection is proved.

Practical Activity 2

To Understand Total Internal Reflection

When light hits an interface between two different media, it can behave in two different ways. Typically, the light partially refracts (bends) and partially reflects. The refractive index of the material is what determines how fast light travels in a material. Light travels about one and a third times faster in air than in water. Learn about total internal reflection in this activity as shown in Fig 3.10.

Material Required

- Laser pointer (preferably green)
- Empty 2-liter soda bottle (clear)
- Rubber plug
- Bucket
- Water

Procedure

1. Make a circular hole close to the bottom of the empty soda bottle. The hole should be about 1 cm in diameter; big enough so that the stream is clear, small enough so you can observe the guided light for long enough to see the effect. Plug the hole with the rubber plug or your thumb and fill with water.
2. Situate the soda bottle above the bucket. Try this a few times so the area stays dry. You might want to have an assistant hold the bottle.
3. Aim the laser pointer through the soda bottle to the hole. As a safety precaution, do not point the laser at anyone! The laser light can reflect and refract in unintended directions.
4. Remove the plug and allow the water to pour into the bucket.
5. You should be able to see a green splash of light where the water lands in the bucket and some of the reflections of the green light in the stream of the water. The light is being guided through the water, which has a higher refractive index than air. You can perform this experiment with different clear materials such as glass.
6. Turn off the laser before the water level gets to the hole.
7. This experiment makes use of total internal reflection that occurs in optical fibre. Typical optical fibre is made from glass and there is a core and a cladding. The core is where the light is guided and has a slightly higher refractive index than the cladding.

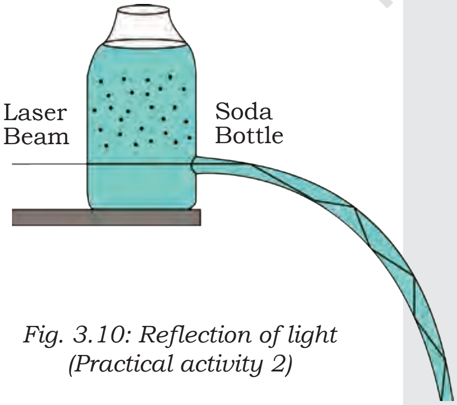


Fig. 3.10: Reflection of light (Practical activity 2)

Total internal reflection

When light hits an interface between two different media, it can behave in two different ways. The light partially refracts and reflects. A special phenomenon occurs when light passes from a higher refractive index medium to a lower refractive index medium. The refractive index of the material determines speed of the light in that material.

Example

We can take the interface between glass and air as an example shown in Fig. 3.11. Glass has a higher refractive index than air. When light passes from glass to air, at all angles less than a certain critical angle say θ_c, the light gets transmitted inside the air. But when the angle is greater than the critical angle then all of the light gets reflected inside the glass. This reflection of light is called total internal reflection.

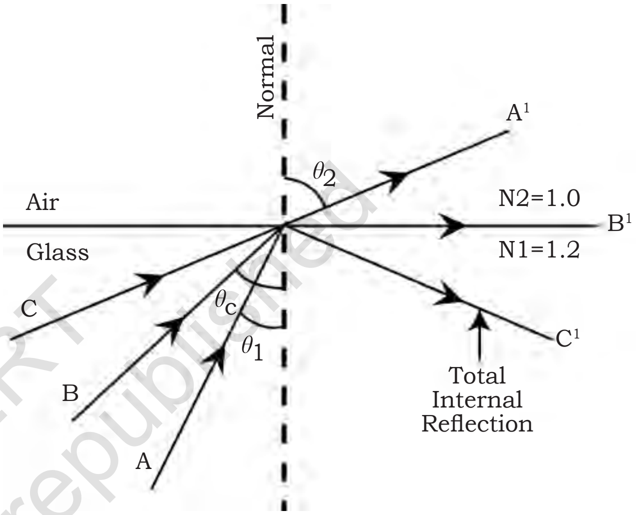


Fig. 3.11: Total internal reflection

Fig. 3.11 shows three rays of light A, B and C. When light travels from medium of glass which is denser to the second medium air which is rarer, it bends away from the normal. Light ray A shows the first case of refraction. Light ray B shows the refracted ray which becomes parallel to the surface of glass at a particular angle called as *critical angle*. Now, at any angle greater than this critical angle (θ_c) the light will be reflected inside the glass only as shown by light ray C.

Fig. 3.12 shows the structure of the fibre optics. It shows the way the total internal reflection of light takes place inside the core. The refractive index of core is larger than the cladding. Due to the difference in the refractive index between the core and cladding, light is confined to the core only. But the angle of light entering the fibre must be greater than the critical angle to enable total internal reflection.

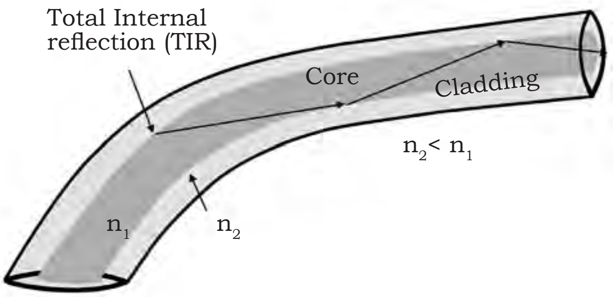


Fig. 3.12: Propagation of light through fibre by total internal reflection

Because of this light passes through the glass fibre for long distances.

Classification of optical fibres

Optical fibres can be classified based on the materials used and mode of propagation of light.

'Mode' refers to the number of paths for the light rays within the cable.

Material based classification

Based on the material, optical fibres are classified into two types: Glass fibres and Plastic fibres.

Glass fibres

Most of the optical fibres are made up of glass. Glass contains a material known as silica. Silica is made from sand.

Plastic fibres

The plastic made fibres are obtained from polymers like poly methyl meta acrylate (PMMA), polyethylene (PE), polystyrene (PS). They are useful in the harsh environment where greater strength is required.

Comparison between plastic and glass fibres

1. Plastic fibres are more flexible than the glass fibres. The flexibility is required in the medical applications of endoscopy.
2. Plastic fibres are used for short distance communication since they have lesser operation temperature ranges for computer applications.

Classification based on modes of propagation

When the light wave is guided through the optical fibre, it exhibits certain modes. These modes can be thought of as a ray of light. Modes of the fibre are classified into two types, namely single mode and multimode fibres. Multimode fibres can further be classified as step index and graded index.

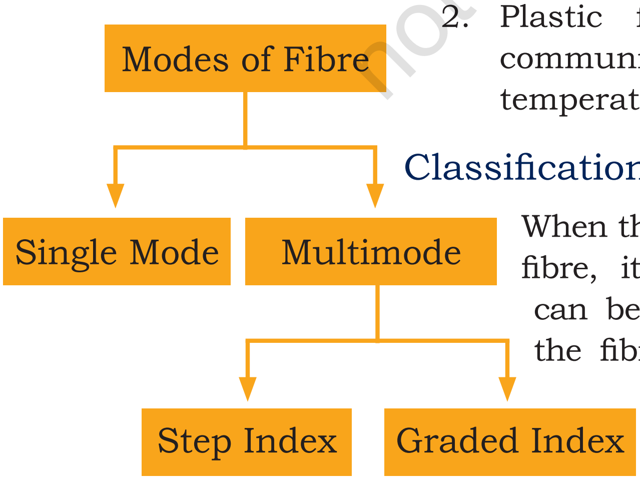


Fig.3.13: Modes of fibre

Single mode

As the name suggests, in case of single mode only one light ray or mode is used to send the data for transmission as shown in Fig. 3.14. Data travels in the form of light signals.

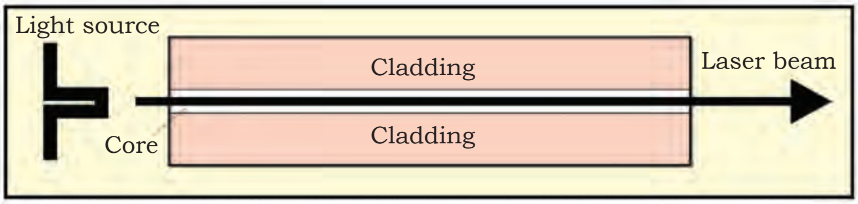


Fig. 3.14: Single mode fibre

Multimode fibre

As the name implies, multimode allows more than one modes like two, three or more to propagate along the fibre. The multiple modes move through the core in different paths (Fig. 3.15).

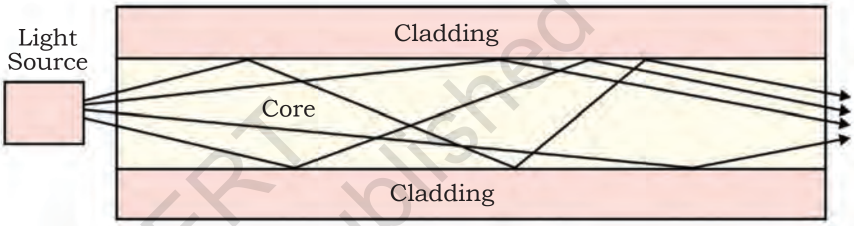


Fig. 3.15: Multimode fibre

Multimode can further be divided into step index and graded index.

Step index fibres

In step index fibres, the light rays propagate in zigzag manner inside the core as shown in Fig. 3.16. It shows the sudden change of light along the fibre like in a staircase or ladder. LED sources are used to launch light in this type of fibre.

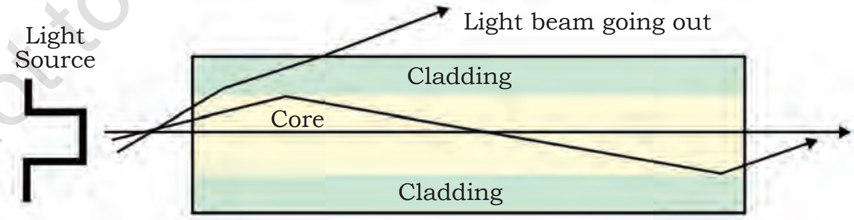


Fig. 3.16: Step index fibre

Graded index fibres

In graded index fibre, the light rays propagate in the form of skew rays or helical rays inside the core of the fibre as shown in Fig. 3.17.

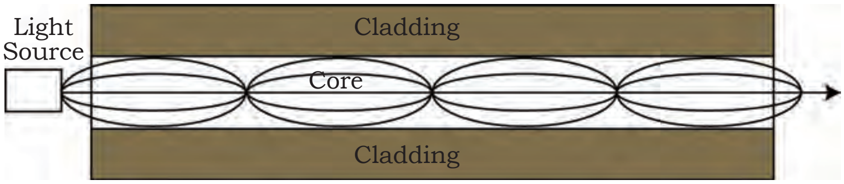


Fig. 3.17: Graded index fibre

Comparision of single mode and multimode fibres

S.No.	Single mode	Multimode
1	Only a single light ray passes through the core of the fibre.	More than one light ray travels along the fibre core.
2	They are used for long distance communication (50 to 60 Km.)	These fibres are used for short distance communication such as building or campus upto 10-15 Km.
3	It has higher bandwidth and less attenuation.	It has lower bandwidth and higher attenuation.
4	It allows less dispersion.	It allows more dispersion.
5	LASER (Light Amplification by Stimulated Emission of Radiation) beam are used to pass the light in the fibre.	LED (Light emitting diode)is used to pass the light in the fibre.
6	It is best suitable for WAN (Wide area network), MAN (Metropolitan Area network), campus, etc.	It is best suitable for LAN (Local area network).

Optical fibre communication

Optical fibre communication is known for transferring digital data. It requires light source for transmission. LASER or LED is the light source for optical fibre transmission. Fig. 3.18 shows the transmission of digital data through the optical fibre. The digital data in form of 0's and 1's is passed through the transmitter. The receiver receives the data and produces the output.

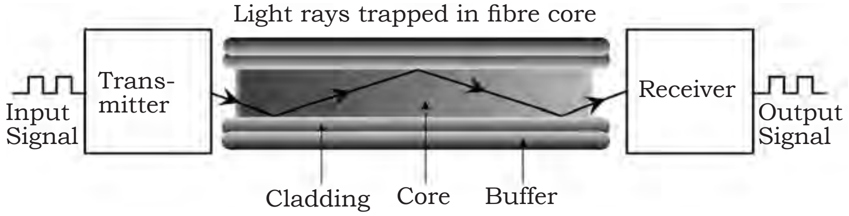


Fig. 3.18: Digital data transmission in fibre optics communication

Elements of an optical fibre communication system

Optical fiber communication system consists of transmitter stage, receiver stage and optical fibre as a medium of propagation as shown in Fig. 3.19. The transmitter stage consists of light source (Light Emitting Diode or LASER) and drive circuitry. The receiver stage consists of photodetector (photodiode or PIN Diode), an amplifier and a signal restorer. Now we will discuss in detail the stages of optical fibre communication system.

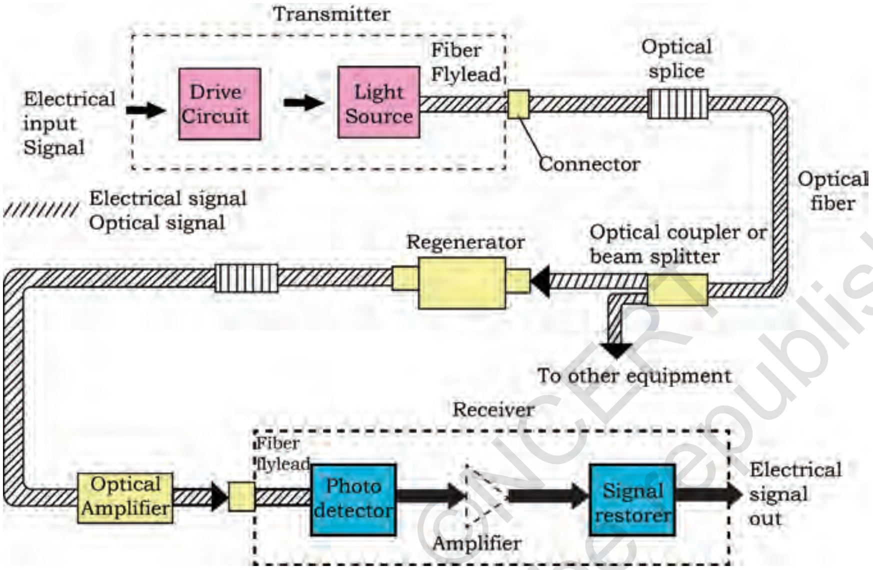


Fig. 3.19: Elements of optical fibre communication system

Transmitter

The transmitter transmits optical light to the fibre cable. It consists of interface circuit, driver circuit, and optical source as shown in Fig. 3.20.

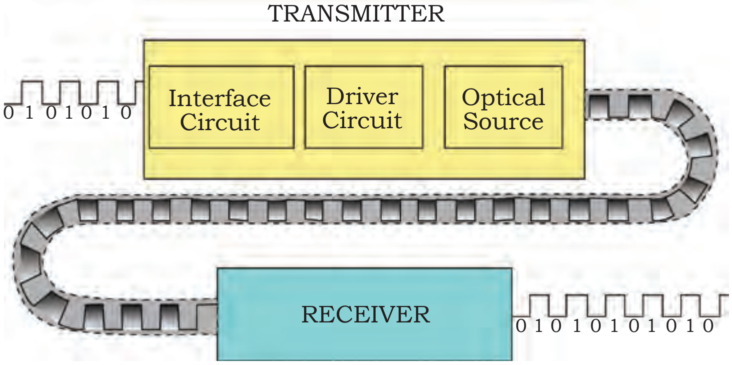


Fig. 3.20: Transmitter in optical fibre communication

Interface circuit: It processes the electrical circuit.

Driver circuit: It processes the input electrical signal, which contains information for the light source.

Optical source: It produces the light signal for the optical fiber. It can be LED or LASER.

Transmission channel

It consists of a fibre cable between transmitter and the receiver. This transmission channel transmits optical light from one end to another. Other components in fibre optics are as follows:

Optical Coupler or Splitter: Optical fibre coupler directs the beam of light from main fibre to other two or more fibres. Alternately, it can be said that coupler splits the light propagating inside main fibre to branching fibre.

Optical Connector: It is for temporary joints between two individual optical fibres that are broken or to be joined for communication. By using connectors, we can connect or disconnect optical cable as and when required.

Optical Splice: It is used to permanently join two individual optical fibres which are broken.

Receiver

Optical signal is applied to the optical receiver. Receiver stage consists of photo detector, signal amplifier and signal restorer as shown in Fig. 3.21.

Photodetector: It converts optical signal into electrical signal.

Signal amplifier: It is used to improve signal quality by removing the noise to achieve better quality of the signal.

Signal restorer: It converts amplified signal for restoring.

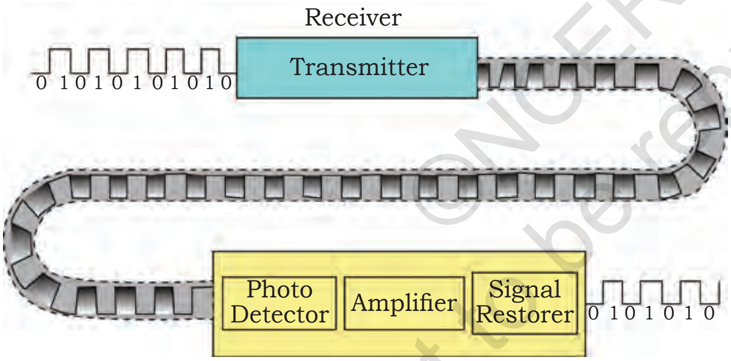


Fig. 3.21: Receiver in optical fibre communication

Assignment

Name of the element of optical fibre communication	Feature
Transmitter	
Interface Circuit	
Driver Circuit	
Optical Source	

Optical Receiver	
Transmission Channel	
Optical Coupler or Splitter	
Optical Connector	
Optical Splice	

Light sources for optical fibres

Fibre optics is used for the transmission of light from one end to another. Hence, at transmitter side a source is required which can emit light and inject into the fibre. There are two main light sources used in the field of fibre optics.

(a) LED (Light Emitting diode)

(b) LASER (Light Amplification by Stimulated Emission of Radiation) beam

Fig. 3.22: Light emitting diode

a) LED: The LED diode converts electrical energy into light energy which can inject into the fibre optics. When current is passed to LED, it emits light. It is an incoherent source of light meaning it is not focussed in a particular direction like a bulb. LED appears in a transparent capsule usually with a lens to let the light escape and to focus on it. They are used in traffic signals, microprocessors, digital computers, DJ's, etc.

b) LASER: A laser diode is an LED with a highly focussed beam of light, i.e., it is coherent in nature as shown in Fig. 3.23. For single mode fibre, lasers are used widely. Remember that laser beam of light cannot be seen with naked eyes otherwise it can damage the retina of the eyes.

Fig. 3.23: LASER source

Losses in optical fibres

The optical fibre does not experience the loss in terms of intensity of light. However, the presence of impurities, scattering at the edges, geometry of structure and dispersion of light causes some losses. In optical transmission, light is a carrier of data which transmits the optical signal in the cable from one end to another.

The optical transmission media consists of three basic elements, i.e., transmitter, receiver, and optical media. Losses may occur while transmitting. The optical fibre does not experience the loss in terms of intensity of light. However, the presence of impurities, scattering at the edges, geometry of structure and dispersion of light causes some losses. Due to decrease in the intensity or spreading of the light in different directions, the signal carrying information/data may become weak and not be able to transmit the data at faster rate. This is because of degraded signal. This degradation of signal may occur due to attenuation and dispersion. Fig. 3.24 shows the signal degradation in optical fibre. This attenuation and dispersion mainly occur when light traverses along the length of the cable transmission channel. Attenuation limits the magnitude of the optical power transmitted, whereas dispersion limits the rate at which data may be transmitted through the fibre, since it governs the temporal spreading of the optical pulses carrying the data.

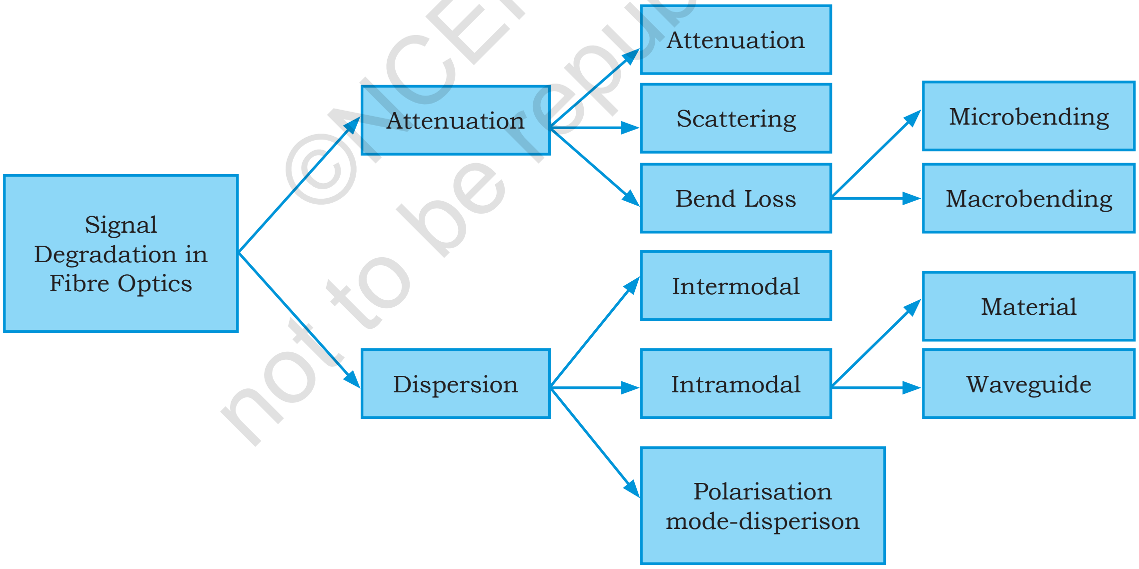


Fig. 3.24: Classification of signal degradation

There are various types of losses in optical fibre communication. Some of them are explained below.

Attenuation

The strength of the light signal goes on decreasing as it travels along the length of fibre. This is termed as *attenuation*. Hence, it determines maximum unamplified or repeater-less distance between transmitter and receiver. Attenuation is measured in logarithmic unit of **decibel (dB)**. The decibel is used for comparing the power levels and is defined as a ratio of input (transmitted) optical power P_i into the fibre to the output (received) power P_o from the fibre as—

$$\text{Number of decibels (dB)} = 100 \log \frac{P_i}{P_o}$$

In optical fibre communication attenuation can also be expressed as decibels per unit length or rate of loss per unit length(dB/km) as

$$\alpha_{dB} L = 10 \log \frac{P_i}{P_o}$$

α_{dB} = signal attenuation/length in decibels. It is a fibre loss parameter

L= Length of the fibre cable

It is directly proportional to the length of the fibre cable. It means that as length or distance of communicating medium increases attenuation increases. When the light signal reaches the receiver, it has very low strength. Because of this attenuation, it is difficult to extract the information from the light signal. Since light signal is in digital form (0's and 1's), when it is weakened it becomes difficult to distinguish between the 0's and 1's. The bits sometimes becomes so weak that the bit 1 may represent '0'. Hence, to rectify this problem of attenuation a device known as amplifiers or repeaters are required to regain the strength of the signal. These amplifiers are added before the signal is sent to the receiver. They restore the strength of the weak signal and finally increase to an appreciable level at receiver. The attenuation is caused due to the absorption, scattering loss and bend loss in optical fibres.

Absorption

It is a type of attenuation basically caused by the fibre material. Light is absorbed by the fibre material and its energy is converted to heat due to presence of the impurities contained in the fibre material. Fibre is made up of glass and this glass contains impurities such as iron, copper manganese, etc. Presence of these impurities causes dispersion.

Scattering

It means light is dispersed in all directions with some of the light escaped through the fibre core. Scattering is caused because of the structural imperfection in the fibre material. In case of scattering loss, light is radiated from the fibre as shown in Fig. 3.25, i.e., light is scattered in different directions. Glass fibre absorbs the light signal and instantly re-emits the light in another direction that are considered as scattering.

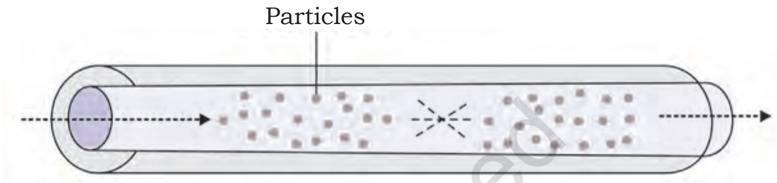


Fig. 3.25: Scattering of light in optical fibre cable

Bend loss

Incorrect fibre optic handling is one of the common problems that can results in fibre optic loss, like bend loss as shown in Fig. 3.26. When fibre optic cable is bent it causes loss of light in the fibre. There are two general types of bends. The first is micro bending, and the second is macro bending.

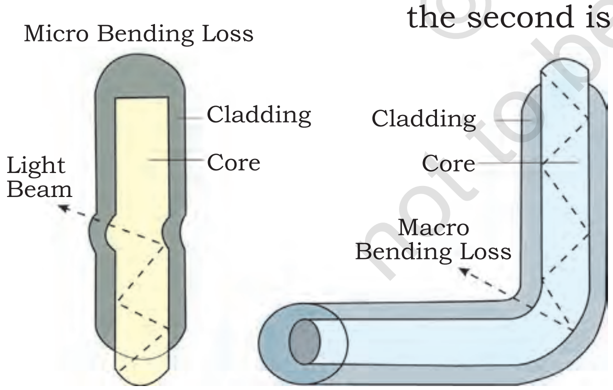


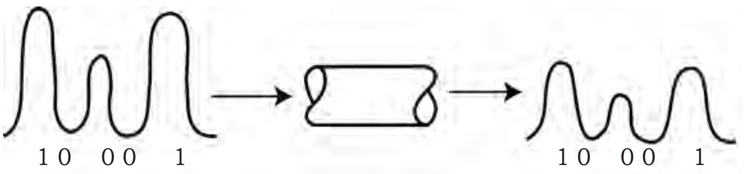
Fig. 3.26: Macro and micro bending in optical fibre cable

Micro and macro bends are common problems in installed cable systems because they can induce signal power loss. It occurs when the fibre core deviates from the axis and can be caused by manufacturing defects, mechanical constraints during the fibre laying process, and environmental variations such as, temperature, humidity, or pressure during the fibre's lifetime.

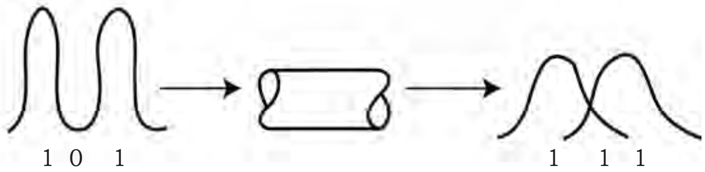
Macro bending happens when a bend in the radius of the fibre is two millimetres or more. To minimise the bend loss, the following points should be considered:

- Deviation of fibre core from axis
- Manufacturing errors
- Environmental factors like temperature, humidity, or pressure should be monitored.

Dispersion



Attenuation-reduces power



Dispersion-spreads the pulse

Fig. 3.27: Attenuation and dispersion

Dispersion refers to the broadening or spreading of the light pulse as they travel through the fibre. Overlapping of the two signal pulses at the output of the fibre end creates error at the receiver output in transmission channel. It limits the bandwidth of the fibre. In other words it limits the information carrying capacity of the fibre as shown in Fig. 3.27. When a short pulse of light travels through an optical fibre its power is 'dispersed' in time so that the pulse spreads into a wider time interval.

There are four sources of dispersion in optical fibres. Dispersion is classified as:

(a) Intermodal dispersion

(b) Intramodal dispersion

(c) Pulse mode dispersion

Intermodal dispersion

Intermodal dispersion occurs in multimode fibre as shown in Fig. 3.28. When a light pulse is injected into the fibre all of the light energy does not reach the end of the fibre simultaneously. In multimode fibres different rays travel inside the fibres with different velocity and they arrive at the fibre end at different times. But sometimes there is overlapping of the rays at the fibre output. Because of this the ray is spread or dispersed

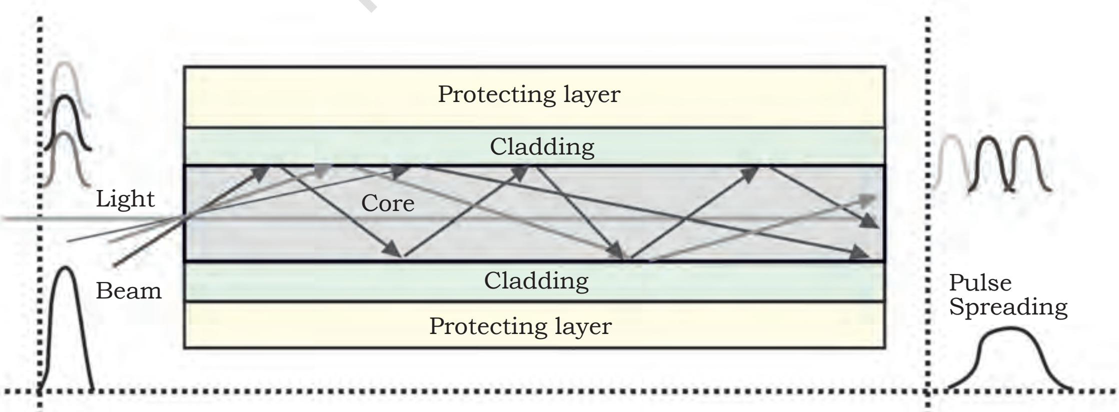


Fig. 3.28: Intermodal dispersion

and it is difficult to distinguish between them at the output of the receiver. Pulses of the signal broaden or spread and they overlap to each other. After certain distance it is difficult to distinguish these pulses. This can be due to the material composition or structure deformities of the fibre. Hence, it leads to pulse spreading at the output which leads to loss of information. For example, if we are sending 101 as digital bit then at receiver end it is received as 111. Hence, it becomes necessary to eliminate the problem of dispersion. This type of dispersion is negligible in single mode fibre since in single mode only one ray travels through the fibre.

Intramodal or chromatic dispersion

Intramodal dispersion is also known as chromatic dispersion. Intramodal dispersion mainly occurs in single mode fibre where single ray is used to carry the information as shown in Fig. 3.29. It occurs because a light pulse is made up of different wavelengths, each travelling at different speeds down the fibre. For example, white light has seven colours and when it passes through the fibre the blue light travels faster and redlight travels slower. Hence, total difference in the width causes the pulse to be broadened. At the end of the receiver output the pulses get overlapped to each other if two pulses travel through the fibre. If there is a large overlap the detector is unable to detect the signal. Hence, we get an error at the output. Therefore, it is difficult to retrieve the information at the output of the receiver. These different propagation speeds reduce the signal-to-noise ratio (SNR) and increases bit error in the information received.

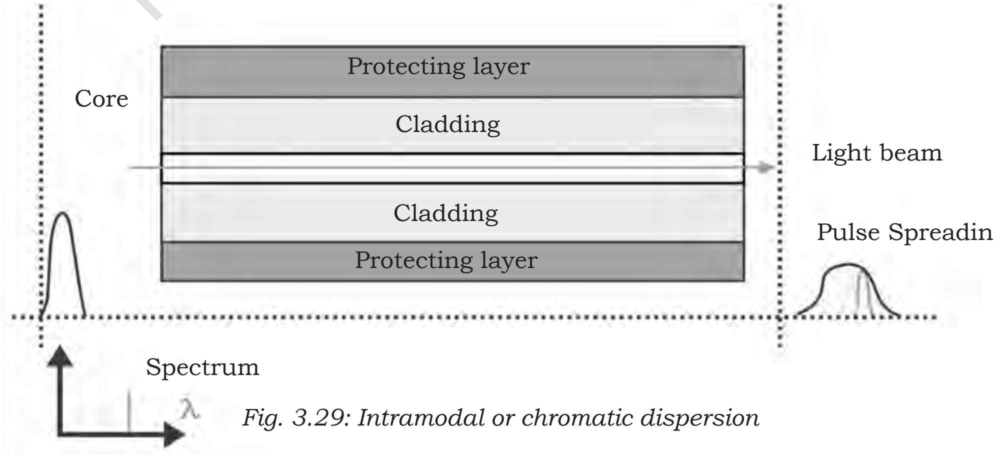


Fig. 3.29: Intramodal or chromatic dispersion

Intramodal dispersion is divided into two parts—

- Material dispersion
- Waveguide dispersion

Material dispersion

Glass is a dispersive medium, i.e., its refractive index is a function of its wavelength. An optical pulse travels in a dispersive medium. The pulse is composed of different wavelengths each travelling at a different velocity, its width spreading. This type of dispersion mainly occurs due to the property of glass. Glass is used to make fibre but it has an important property. It splits the light into seven colours having different speeds. For example, a prism is made up of glass and when white light is passed through it, it is split into 7 colours as shown in Fig. 3.30. This type of dispersion is due to the material property of fibre glass, which leads to spreading of the light inside the fibre and they arrive at fibre end at different times. Material dispersion can't be removed since it is due to the material of the fibre itself.

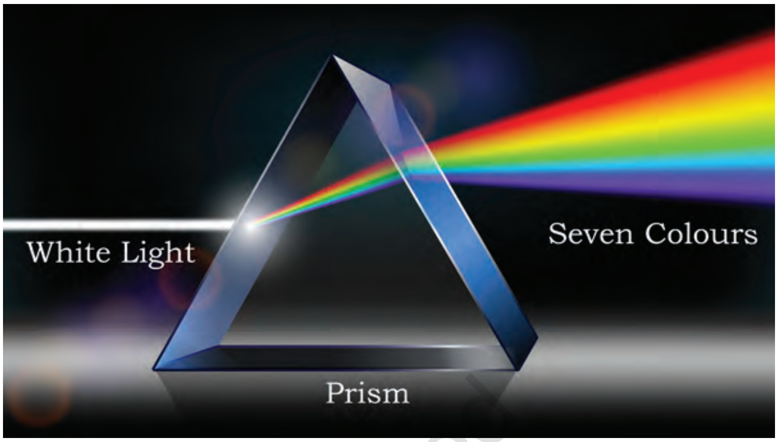


Fig. 3.30: Light is passed and split into seven colours by prism

Waveguide dispersion

This type of dispersion occurs because a single mode fibre restricts only about 80 per cent of the optical power to the core and the rest 20 per cent of light propagating in the cladding travels faster than the light confined to the core (Fig. 3.31). Hence, more rays travel in cladding than in the core. This type of dispersion mainly occurs in single mode fibre since it has small core diameter.

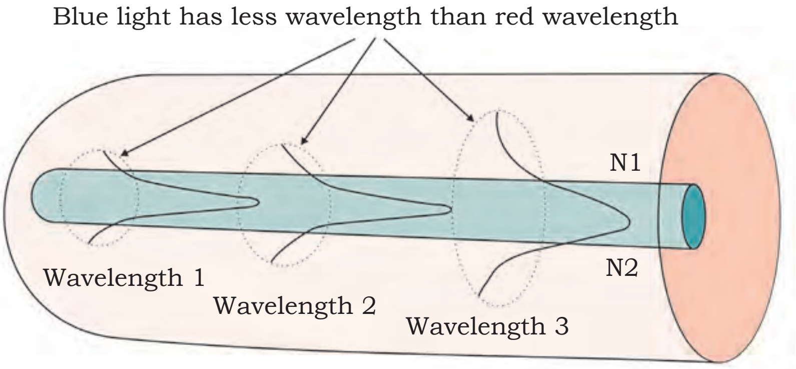


Fig. 3.31: Waveguide dispersion

Polarisation mode dispersion

Polarisation mode dispersion (PMD) is a basic property of single-mode fibre and it affects the magnitude of the transmission rate. When there is a difference in propagation speeds of the energy of a given wavelength, which is split into two polarisation axis perpendicular to each other as shown in the Fig. 3.32 then it results in polarisation mode dispersion. The main causes of PMD are non-circularities of the fibre design and externally applied stresses on the fibre such as macro bending, micro bending, twisting, and temperature variations. The PMD causes the transmission pulse to broaden when it is transmitted along the fibre. This phenomenon generates distortion, increasing the bit error rate (BER) of the optical system. The consequence of PMD is that it limits the transmission bit rate.

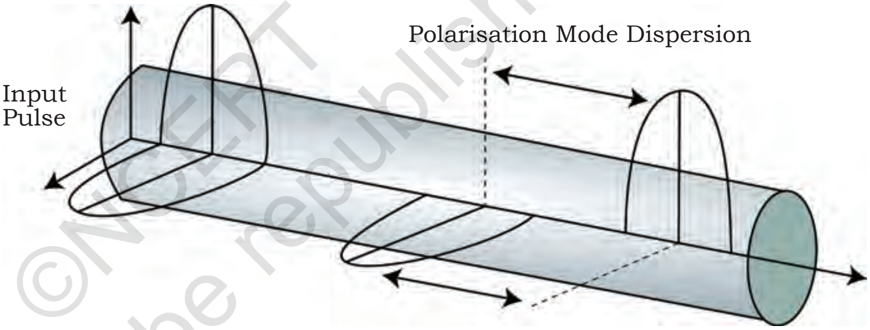


Fig. 3.32: Polarisation mode dispersion

Check Your Progress

A. Multiple Choice Questions

1. Buffer coating in the fibre optics outside the core-cladding interface provides ______________.
   (a) mechanical strength
   (b) propagation of light
   (c) propagation of electricity
   (d) physical strength
2. Speed of light coming from the sun to earth is ________.
   (a) 300000Km/sec
   (b) 200000Km/sec
   (c) 100000Km/sec
   (d) 400000Km/sec

3. Method of reflection on the surface of smooth polished mirror means _______________ of light.
   - (a) bouncing
   - (b) absorption
   - (c) transmission
   - (d) bending
4. Method of refraction at the air-water interface leads to _______________ of light.
   - (a) bouncing
   - (b) scattering
   - (c) bending
   - (d) transmission
5. If light is passed through the glass to air and angle of transmitted light is greater than the critical angle then it leads to _______________.
   - (a) total internal refraction within glass
   - (b) total internal refraction within air
   - (c) total internal reflection within glass
   - (d) total internal reflection within air
6. White light coming from the sun is composed of _______________ colours.
   - (a) seven
   - (b) eight
   - (c) six
   - (d) nine
7. Phenomena of total internal reflection takes place in _______________.
   - (a) optical fibre
   - (b) coaxial cable
   - (c) twisted pair of cable
   - (d) shielded twisted pair of cable
8. Single mode fibre is used in carrying _______________ of light.
   - (a) two-rays
   - (b) one-ray
   - (c) three-rays
   - (d) multiple-rays
9. Light through the optical fibre propagates inside _______________ by total internal reflection.
   - (a) core
   - (b) cladding
   - (c) jacket
   - (d) buffer-coating

10. Optical splitter is used for ______________.
    (a) splitting the signal to other devices
    (b) merging the signal to other devices
    (c) transmitting the signal
    (d) receiving the signal
11. Optical regenerator is responsible for ______________ the signal.
    (a) suppressing
    (b) regenerating
    (c) multiplexing
    (d) demultiplexing
12. Optical fibre splice is used for _________ the fibres ends.
    (a) connecting
    (b) joining
    (c) disconnecting
    (d) soldering
13. Photodetector converts ______________.
    (a) optical signal to heat
    (b) optical signal to electrical signal
    (c) electrical signal to optical signal
    (d) electrical signal to heat
14. Structure of the fibre consists of elements like _________.
    (a) core
    (b) cladding
    (c) core and cladding
    (d) core, cladding and buffer
15. Intermodal dispersion occurs in ______________.
    (a) single mode fibre
    (b) multimode fibre
    (c) both single mode and multimode fibre
    (d) coaxial cable

B. Fill in the Blanks

1. If you dip a spoon inside a glass filled with water then the spoon appears to be _____________.
2. If white light is passed through the prism the light splits into _____________colours.
3. Total internal reflection is a method which allows the light to pass through the _____________part of the fibre.
4. Light appears to flow like a fountain of water because of _____________.
5. When light is passed from glass to air at particular angle known as critical angle then at that time light is _____________ to the surface of the glass.

6. Diameter of the core is __________ than the cladding.
7. Buffer-coating is made up of __________.
8. Buffering to the core-cladding provides __________.
9. Speed of light becomes __________ when it travels from rarer medium to denser medium.
10. Speed of light becomes __________ when it travels from denser medium to rarer medium. Signal restorer converts signal __________ for restoring.
11. The receiver stage consists of __________, __________ and __________.
12. Intramodal dispersion is also known as __________.
13. LED which does not focus in a particular direction is called as __________ source of light.
14. In __________ light rays propagate in helical manner inside the core.
15. Attenuation occurs because of ________, ________ and __________ losses.

C. State whether True or False

1. Combining the colours of rainbow we get white light.
2. Speed of violet colour is less than red colour in the rainbow.
3. Plants reflect the sunlight falling in them.
4. The glass used in making core is very hard and cannot be broken easily.
5. Thickness of fibre is greater than thickness of coaxial cables.
6. Refractive index of core is greater than that of cladding that is why light is confined to the core part only.
7. Total internal reflection takes place in the cladding section of the fibre.
8. Cladding of fibre is also responsible for the propagation of the light through the fibre.
9. Information security cannot be achieved with the help of optical fibre.
10. Fibre optic cables are not used for sending the information from one computer to another.
11. Fibre optic cables are very heavy and bulky in weight than coaxial cables.
12. Speed of carrying the information in fibre optics is very fast compared to other wired communication media.
13. LED light rays are not used with multimode fibres.
14. Laser beam is used to inject light in single mode fibre.
15. Fibre optic cables are very cheap in cost.

NOTES

NOTES

D. Answer the following in one sentence

1. Name the material by which optical fibre is made.
2. Name the various structural elements of optical fibre.
3. Why optical fibre core and cladding is covered with buffer-coating?
4. The Snell's Law is related to what?
5. How does rainbow appear in the sky?
6. List the seven colours of the rainbow and draw them in your notebook.
7. What is electromagnetic spectrum?
8. In which range of electromagnetic spectrum does fibre optics lie?
9. How light is injected into a fibre?
10. What type of information is carried by light, i.e., analog or digital and why?
11. What element is applied if the signal is weakened along the length of the fibre?
12. What is the difference between the attenuation and dispersion?
13. What is the effect of attenuation in the fibre?
14. What is the effect of dispersion in the fibre?

E. Answer in Brief (50 words)

1. Draw a labelled diagram showing the structure of optical fibre.
2. Name the different modes of optical fibre.
3. Compare step and graded index fibres and state which one is best.
4. Why optical fibre is used for transmitting information?
5. Define total internal reflection, critical angle and at what angle the light is injected inside the fibre?
6. Write and draw at least seven places in real life, for example, in the fields of medicine, military, etc., where total internal reflection takes place.
7. What is critical angle when reflection of light takes place from glass to air in a fibre?
8. Explain how light passes through fibre.
9. Draw the structure of fibre and briefly explain each parts.
10. What are the elements of optical fibre transmission link?
11. What are the elements of optical fibre receiver link?
12. How is the attenuation in fibre measured?

13. Why is it not possible to measure material dispersion? Give example.
14. What are various optical sources and what types of light is emitted by them?
15. Why does dispersion occur? What are the different types of dispersion?
16. What do you mean by bend loss? Explain.

Notes